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DAVIDSON LABORATORY

Report 1138

STEVENS INSTITUTE OF TECHNOLOGY

CASTLE POINT STATION
HOBOKEN, NEW JERSEY

HIGHWAY CENTER-BARRIER INVESTIGATION

Part I. Accident Analysis

by

M. Peter Jurkat

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ABSTRACT

With the rapid increase in traffic volume on New Jersey State highways came a sharp increase in head-on collisions on undivided and inadequately divided roadways. In response to the situation, the State Highway Department installed concrete median barriers, thereby effectively reducing the incidence of head-on collisions. This study examines the effect these barriers had on the over-all accident records of roadways on which they installed. On the basis of a comparison of the records of these roadways with those of roadways divided by other means, and a historical analysis of records before and after barrier installation, the study concludes that the accident records of barrier-divided roadways are no worse than those of roadways divided by other means, and that where the barrier was installed along the major part of a roadway the roadway's accident record improved.

INDEXING KEYWORDS

Highway Safety

Highway Accident Studies

Highway Center Barriers

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INTRODUCTION

For the last two decades, opposite roadways of major highways have been separated by barriers or medians in an attempt to reduce the frequency of head-on collisions accompanying the spectacular rise in traffic volumes. The cost of the head-on crash in lives and damage -- often high in spite of moderately wide medians -- led the New Jersey State Highway Department (NJSHD), in the 1950's, to adopt a concrete center barrier as a positive means of eliminating crossover incidents on the major highways of New Jersey. The "Summary of Motor Vehicle Traffic Accidents" for the year 1964, compiled by the Traffic Safety Service of the New Jersey State Division of Motor Vehicles, shows that of a total of 198 two-vehicle accidents, occurring between intersections, 115 involved fatalities (58 percent). None of these occurred on any road segment on which New Jersey had installed concrete center barriers 32-inches high.* It would therefore appear that the New Jersey concrete barrier which is 32-inches high has been performing its intended function, and that the problem of determining collateral effects on traffic safety may now be considered.

The purpose of the present study (Phase I of a two-phase investigation) was to examine all existing accident records for road segments on which concrete barriers (of any configuration) were installed, and to compare these records with those for other road segments in the system.

The barrier under consideration is known as the New Jersey Concrete Barrier Curb. In general, it is a continuous block of concrete with curved sides resulting in a width of 30 inches at the bottom and 9 inches at the top. Forms have varying dimensions, differing primarily in height.

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*Verbal communication from the New Jersey State Department of Transportation. New Jersey began to install the 32-inch-high barriers in 1960. Originally, the barriers were 19-inches high.

Since this barrier generally prevents the passage of automobiles from one side of the roadway to the other, its installation necessitates the addition of turn-arounds and the elimination of intersections, and is often performed in conjunction with road-widening and the installation of traffic controls at remaining intersections. These additional modifications also affect traffic, and make the influence of the divider itself more difficult to ascertain.

In this investigation, therefore, an attempt was made to determine specific effects on safety; that is, the results of barrier installation and the results of attendant roadway improvement. The investigators approached the problem by using a multivariate statistical analysis, in an effort to isolate the effects which various highway parameters, including the barrier, have on accidents. In the final analysis, only reported accidents involving injury were considered, and no attempt was made to evaluate the relative intensity of accidents.

Part II of this study (in process) is concerned with scale-model tests intended to provide a better understanding of the vehicle-barrier impact phenomenon.

SUMMARY OF RESULTS AND CONCLUSIONS

Below is a brief summary of the principal results and conclusions of both Part I and Part II of the "Highway Center-Barrier Investigation." Substantiating data for these results and conclusions which do not appear in this report (Part I) may be found in Davidson Laboratory Report 1139 entitled "Highway Center-Barrier Investigation; Part II, Model Study" (in process).

RESULTS

(1) For the road sections which by 1963 had been divided by the New Jersey Concrete Barrier Curb (and are examined in this study), the over-all safety record for 1963 is 180 injury-accidents per 100-million vehicle miles, while for road sections divided by means other than the Barrier Curb the corresponding record is 260 injury-accidents per 100-million vehicle miles (Table 2, Part I, p. 16). Historically, accident records for periods before 1963 showed that 35 percent of the road sections on which the concrete barriers were installed, between 1955 and 1962, had fewer accidents than before installation of the barriers; records for 25 percent of these sections were poorer than earlier records; and records for 40 percent were essentially unchanged (Table 4, Part I, p. 23).

(2) In the presence of barriers and other kinds of dividers, the factors which most influence variations in the accident rate are intersections per mile and number of acceleration- and deceleration-lanes per mile (pp. 17 and 18, Part I).

(3) Historically, the accident record of a road section improves in direct relation to the amount of barrier installed. Of the sections to which reference is made in the historical results of (1), above, those with a record of improvement were barriered for an average of 71 percent of their length and those with retrograde records were barriered for 32 percent of their length (Table 4, Part I, p. 23).

(4) The safety record of undivided four-lane road sections is inferior to that of divided road sections. Divided road sections with access control have a better record than do divided road sections which have no access control. Both statements hold for every traffic-volume rate examined (Fig. 1, Part I*).

(5) The physical scale model used qualitatively simulates actual full-scale tests (Figs. 9 and 10, Part II). Tests at the equivalent of up to 90 miles per hour full-scale were conducted, with impact angles of up to 16 degrees. In no case did the vehicle model jump the model of the 32-inch barrier (p. 18, Part II).

CONCLUSIONS

(1) The 32-inch New Jersey Concrete Barrier Curb is an effective means of separating automobile traffic in opposing roadways. It thereby greatly reduces the risk of head-on collisions.

(2) Collateral effects on traffic safety are not deleterious, insofar as accident rates are concerned. The investigation showed that, on the average, there was improvement in accident records after a barrier curb was installed, provided the barrier extended throughout the road section. Where only a small percentage of the road section was barriered, the average number of recorded accidents increased.

*All figures for Part I appear at the end of this report.

METHODS OF ANALYSIS

This report contains three analytical studies:

(1) A graphical study intended to give a general overview of the data and to derive a relationship between accidents and traffic volume for use in the two following studies.

(2) A detailed, extensive, multivariate regression analysis for a given year, intended to determine precise relationships between accidents and various road parameters.

(3) A study to provide comparison ratios for road-section records before and after the installation of the concrete barrier.

All applicable data points were used in all studies; hence the work is a population analysis as opposed to an analysis of samples.

METHOD USED IN GRAPHICAL ANALYSIS

A graphical analysis was developed to obtain basic information about the fundamental relationship of both traffic volume and gross characteristics of roadway design to accident occurrence. No assumptions were made about the explicit form of the curves fitted to scatter diagrams of two variables. It may be described for any two variables, one of which is arbitrarily assigned the role of the independent variable while the other is called the dependent variable. Individual cases are ranked according to the magnitude of the independent variable, and an order is thus imposed on the dependent variable. Moving averages are computed for both variables, going from the smaller values of the independent variable to the larger. Corresponding moving averages are calculated for the dependent variable.

Moving-average calculations have the effect of spreading the influence of a particular point over a wider region of the independent variable. For this reason, the points of the moving average will show a cyclical variation

about some trend line in the data. This trend line may be found by averaging the moving-average points in each cycle. A free form line is then fitted to these cycle averages from the peaks and troughs of the cycles; a relationship may be postulated by inspection.

METHOD USED IN MULTIVARIATE REGRESSION ANALYSIS

The multivariate regression analysis is a standard method which fits a sequence of many-dimensional planes to the data, in the form of multivariate linear equations. It may be used when one assumes a specified relationship between a dependent variable and many independent ones. At each step of the analysis one independent variable is added to the regression equation -- namely, the variable which makes the greatest reduction in the sum of the squares of the errors in the dependent variable about its mean. When a pre-assigned level of precision is reached, or if the addition of more variables does not affect the error sum of squares, the analysis is complete, and the remaining independent variables are said to have no effect on the dependent variable. A complete description of the method appears in Chapter 8 of Ralston and Wilf's <u>Mathematical Methods for Digital Computers</u> (John Wiley and Sons, New York, 1960).

METHOD USED IN BEFORE-AND-AFTER STUDY

The before-and-after analysis attempts to determine whether or not the installation of a barrier has had significant effect on a particular road section, by comparing (1) accident records for the road section before the barrier was installed (with the attendant road modifications) and (2) accident records afterwards.

For each year studied, a graph of accident rate* versus Average Annual Daily Traffic (AADT) is fitted to a scatter diagram of all road

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*The "accident rate" equals accidents divided by vehicle miles.

sections in the state highway system. This graph is derived by the method described for graphical analysis (p. 5) and it yields a plot of the average of the accident rates versus AADT. For each road section studied, the actual accident rate is divided by the accident rate for the corresponding traffic volume as taken from the graph. The resulting ratio indicates the relative accident-rate standing of each study section, compared with all road sections with comparable AADT. A ratio greater than one indicates that the road had, relatively, a poorer accident record than other roads with the same volume of traffic; a ratio less than one shows that the road had a better accident record.

For each study section, this ratio is then plotted from year to year -- in particular for the years immediately preceding and immediately following barrier installation.

RESULTS

Because of certain limitations on the scope of the study, no attempt was made to derive data from original sources (police records or counting-station reports). All data were supplied by the New Jersey State Highway Department (now the New Jersey Department of Transportation) and the Division of Motor Vehicles, in the form of tabulations, punched cards, or magnetic tapes.

Initial examination of the data revealed that detailed accident records were available for the years 1961 through 1963 only. It was further discovered that each accident was sited only by route and municipality, plus an indication of whether or not it occurred at an intersection. The resulting inability to locate each accident precisely placed a definite limit on the precision of this study, since in many cases the road barriers did not extend throughout the entire municipality. This meant that all analyses had to be done with road sections defined by municipal boundaries. It also meant that any road parameters used in analysis had to be uniform throughout a municipality; or that, if they were not uniform, the characteristics of the road had to be averaged over the length of the road section within the municipality.

RESULTS OF GRAPHICAL ANALYSIS

The data for this analysis were taken from "1963 State of New Jersey Highway Accident Factors," prepared jointly by the Traffic Safety Service, Division of Motor Vehicles, and the Bureau of Planning and Traffic, NJSHD. This publication breaks each road down into county and municipality sections, and for each section it specifies the manner of road division and the number of lanes, and gives length, AADT, and accident, injury, and fatality rates. The amount of barrier constructed on each section was taken from a special tabulation prepared for this study by the NJSHD, and the extent of access control was read from a punched-card deck of highway characteristics, also

provided by the NJSHD. Only sections exhibiting uniform characteristics throughout a municipality were used in this analysis.

Roadway sections were initially sorted by number of lanes. Only four-lane sections were chosen for study, since no barriers have been constructed on two-lane roads and there are not enough six-lane (or wider) stretches to make a significant analysis.

To gain an understanding of the basic relationship between accidents and traffic volume, a straightforward plot was developed. A good deal of uncertainty was found in the range of volume between 5,000 and 25,000 vehicles a day. A further breakdown was therefore attempted, which yielded three plots, classified by the presence or absence of any kind of roadway division and access control. Two secondary categories were derived in order to include road sections in which manner of division was not uniform throughout a municipality.

This preliminary analysis is summarized in Table 1. The first four categories are mutually exclusive, while the fifth is composed of road sections in both the divided-no-access-control and the divided-access-control categories.

TABLE 1. ACCIDENT RATE (ALL ACCIDENTS), 1963

[Four-Lane Highway Sections Uniform Throughout a Municipality]

Classification	Number of Sections	Total Length (miles)	Average Length (miles)	Average AADT	Total Accident Rate (per 100 mvm)
Undivided	40	66.90	1.67	16,700	532
Fully divided, no access control	115	251.3	2.19	26,900	452
Fully divided, access control	24	42.09	1.76	23,100	244
Partially divided	25	56.77	2.27	21,700	724
Divided; some or full barrier	27	67.33	2.49	43,100	384
All roads, State Highway System	832	1907.3	2.29	13,700	441

To learn more of the role which volume plays in accident rates, plots of accident rate versus AADT were made for the first five categories listed in Table 1. These are presented in Figure 1. Inspection reveals that the major improvement was achieved by dividing the roadways and controlling access.

These graphs present a basic relationship between traffic volume and accidents. An eventual constant slope with increasing volume is apparent. Also apparent is a level of AADT at which each curve increases rapidly to a new, higher level. This value of AADT, however, rises with the installation of barriers and access control.

Because of the nature of the plot, it was assumed that the curve is a third-order polynomial plus an exponential term. This relationship was therefore hypothesized as the mathematical model for the multivariate regression fit of the next study.

RESULTS OF MULTIVARIATE REGRESSION ANALYSIS

In view of the difficulties encountered in the preliminary analysis, in using accident rates based on daily volumes, it was decided to perform the multivariate analysis on the basis of hourly traffic counts. This additional effort yields two advantages. The hourly traffic count reflects conditions at the time of the accident more accurately than does AADT; in addition, more data points are provided, so that statistical tests derived for normally distributed random variables are applicable.

The selection of road sections to be used in the analysis now depended upon the availability of hourly data for them. Since lack of sample size was no longer a problem, it was decided that only the divided-no-access-control category of the graphical analysis would be studied. This eliminated the variability due to access control, which is not a concern of this study. The undivided category was not studied because it was learned that the reason the road sections in this category remained undivided was that they did not exhibit the growth in traffic characteristic of the rest of the state system; they therefore represented a special case not germaine to the problem. The study-universe was hence reduced to four-lane divided

highways with no access control. This universe was further split into road sections divided by the concrete median barrier and sections divided by all other means. All further analysis was performed on these two categories.

All road sections with four lanes which exhibited uniformity in manner of division throughout a municipality, and had uncontrolled access, were drawn from the highway-characteristics deck supplied by the NJSHD. Simultaneously, the precise length of each section within the municipality and the weighted average of the roadway width over this length were calculated. All road sections which showed a record of major modifications after 1963 were eliminated, since the physical characteristics of the roads were measured in 1964.

The calculation of hourly traffic volumes required the assignment of volumes to road sections, because not all road sections contain counting stations. To reduce the magnitude of the job, a few counting stations throughout the state were examined for seasonal and weekly patterns. After graphing daily volume profiles on an hourly basis, it became apparent that for any one week the daily profile of any one of four days -- Monday, Tuesday, Wednesday, or Thursday -- differed little from that of any other of these four days. Friday, Saturday, and Sunday, however, were special cases. Furthermore, if the seasons of the year were broken down in the form

Winter = January, February, March
Spring = April, May
Summer = June, July, August
Fall = September, October, November, December

then the variations in the same day of the week throughout the season were also small.

Because of these considerations, a section-season-hour (SSH) for the four weekdays mentioned above was chosen as the basic sample point. That is, a single hourly volume was assigned to each road section in each season for these four days of the week, and none of the weekend days was included. For each section, 24 hours a day for four seasons yielded 96 sample points.

The average hourly volume for each hour of the day in each season was calculated for each of the NJSHD counting stations near sample road sections. The daily traffic calculated from these hourly averages was then divided by the AADT assigned to the road section on which the counting station was situated. This yielded a seasonal ratio for that station. This seasonal ratio was then applied to the AADT of the sample road section, to yield an average daily volume for that road section in each season. That daily average was then distributed as if taken at the counting station.

Operational problems arose when some counting stations measured the traffic in one direction only. On an hourly basis, one-way traffic cannot be doubled to yield two-way traffic, so the missing direction at a counting station was assigned from another station which had traffic in that same general direction, much as traffic assignments were made to the sample road sections from the counting stations. When major intersections were located between a counting station and the sample road section, that road section was discarded from the sample, except for the case of New Jersey State Route 22, which was too important to ignore. In its case, and in every other case in which the sample road section lay between two counting stations, the hourly volumes were interpolated from both counting stations, instead of being extrapolated from a single station. The reason two-way traffic was an important factor relates back to the inability to locate an accident precisely. Since accidents were known only according to municipality, no assignment to side of the road was possible.

After all eliminations, the final study sample consisted of 14 sections with concrete barriers and 13 sections divided by other means. Of the 14 barriered sections, 7 had the barrier along the entire section length; and 7 were barriered between 60 and 88 percent of total section length (whether or not an accident had occurred where there was a barrier on these latter sections could not be determined). The 13 sections divided by other means had median widths of 2, 13, 16, or 30 feet.

The 14 barriered sections had a total length of 33 miles and carried 213.5 mvm per year; those divided by other means totaled 31 miles in length and carried 153.8 mvm per year. There were 1343 section-season-hours for barriered roads and 1247 section-season-hours for roads otherwise divided.

For each of the SSH's in the sample, values for road and traffic variables were derived. These roadway parameters may be conveniently grouped into geometric, internal-friction, and side-friction measurements.

(1) Geometric Measurements

Length
Outside shoulder, width and type
Roadway width and kind of pavement
Inside shoulder, width and type
Median width and type (for barrier sections, different type numbers were assigned for different heights)
Number of lanes (four in all cases)

(2) Internal-Friction Measurements

Volume of traffic
Truck percentage
Out-of-state-vehicle percentage
Traffic lights per mile
Crossings per mile
Speed limit

(3) Side-Friction Measurements

Merges (acceleration and deceleration lanes) per mile
T-intersections per mile
Driveways per mile

The following three kinds of accidents were found for each SSH:

(1) Total reported accidents

(2) Single-car reported accidents

(3) Reported accidents involving an injury

Initially, total reported accidents were used in the analysis, but in the final calculations only the injury-accidents were used, because a reporting problem exists for minor accidents. Possibly this imposed an artificial downward bias on accidents in the high-volume ranges, since relative speeds and total speeds may be so low that only "fender bender" accidents occur. It was considered a worthwhile price to pay for more accuracy in reporting.

Length, roadway width, and kind of pavement were read directly from the highway characteristics deck mentioned earlier. The manner in which volume was collected has already been mentioned. Information on shoulder width and type, median width and type, and number of traffic lights was supplied by a special tabulation provided by the NJSHD.

Truck and out-of-state-vehicle percentages were gathered by study personnel during several visits to the NJSHD; the percentages were known for the counting stations used in the volume assignments, and were used as found for the sample road sections. However, measurements are not taken at counting stations for all hours of the day and all seasons of the year. When not available for 1963, measurements from the "fall" of 1961 to the "spring" of 1965* were substituted, the closest one available being taken in each instance. This yielded data for 1082 section-season-hours in the barrier category, and 448 section-season-hours in the otherwise-divided category. This disparity is unfortunate, but apparently the barrier roads are the more important ones and many counting stations on the divided highways do not measure truck and out-of-state-vehicle percentages on more than one shift a day. The actual multivariate regression was performed with SSH's for which these percentages were available.

The number of crossings, acceleration lanes, deceleration lanes, T-intersections, and driveways was obtained by actual count during the months of July and August, 1965. This is the reason all road sections which had major modification between 1963 and 1965 were discarded before the final sample was chosen.

Speed limit used for each section was the average of all the speed limits on the section, weighted by the distance over which they were imposed. The statutory speed limits were chosen as they existed in August 1965. Again, this sort of averaging was necessitated -- as before -- by the lack of accident locatability below municipality level.

Accident data were supplied in the form of a magnetic tape suitable for IBM 1401/60 and 7090/94 machines which contained the card images of the

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*As these seasons have been defined for the study (p. 11).

Accident Deck of the Traffic Safety Service of the Department of Law and Public Safety of New Jersey. The deck contained a card for each vehicle in an accident and one for each injury other than the driver's. An accident is reconstructed by combining all cards of a particular case number. It is possible to obtain information on the date, day of the week and hour of the accident, route number and municipality, number of vehicles, severity, driver(s), and any casualty.

Special programs were written to unpack this tape and select those accidents which occurred during weekdays on the road sections under study. These accidents were assigned to one or more of the three accident categories and to the particular SSH's in which they occurred.

All information for an SSH was punched on a single card, in the following format:

Column or Columns	Information
1-3	Route number
4-5	County Code (as per NJSHD Code, Jan. 1962)
6-7	Municipality Code (as per same)
8	Season (1, winter; 2, spring; 3, summer; 4, fall)
9-10	Hour ending
11-12	Volume (in hundreds of vehicles)
13-14	Truck percentage
15-16	Out-of-state-vehicle percentage
17-24	Not punched
25-26	Accidents
27-28	Single-car accidents
29-30	Injury accidents
31-41	Not punched
42-45	Length (in hundredths of a mile)
46	Number of lanes
47-48	Outside-shoulder width (in feet)
49	Outside-shoulder type (0, none; 1, improved; 2, gravel; 5, bituminous concrete; 6, concrete)

[Cont'd]

Column or Columns	Information
50-51	Roadway width (feet, one side only)
52	Roadway type (6, bituminous concrete and sheet asphalt; 7, Portland cement concrete)
53-54	Inside-shoulder width (feet)
55	Inside-shoulder type (0, none; 1, improved; 2, gravel; 5, bituminous concrete; 6, concrete)
56-57	Median width (feet)
58	Median type (0, undivided; 1, earth; 3, concrete; 6, barrier 16- to 24-in. high; 7, barrier 24- to 36-in. high; 9, variable)
59-60	Driveways per mile
61-63	T-intersections per mile (in tenths)
64-65	Merges per mile (in tenths)
66-68	Crossings per mile (in tenths)
69-70	Traffic lights per mile (in tenths)
71-72	Speed limit (in miles per hour)

Initially, an over-all injury-accident rate for both barrier and non-barrier divided sections was calculated. This calculation included the SSH's for which truck and out-of-state-vehicle percentages were not available, and it is shown in Table 2. Since no statistical distribution for accident rates is known, no tests of significance were performed.

TABLE 2. HOURLY INJURY-ACCIDENT RATE, 1963

Classification	Number of SSH's	Number of Injury Accidents	Total Vehicle Miles (millions)	Injury Accident Rate (accidents per 100 mvm)
Barrier sections	1343	385	213.5	180.3
Other-divided sections	1247	405	153.8	260.7

The multivariate regression analysis was performed by the use of the stepwise regression program of the Biomedical Computer Programs written by the Health Sciences Computing Facility of the School of Medicine of the University of California in Los Angeles. It is program number BMD02R of that series. Only those road sections for which truck percentages were available were used in the analysis. The data were so scaled as to give accident rate in accidents per million vehicle miles. The results follow.

(1) Barrier-Divided Sections

The calculated regression equation was

$$y = 5.171 + 0.2716(x_{26})^3 + 0.07115(x_{24})^3 - 19.43 \exp (x_{28} \cdot 10^{-4})$$

$$+ 0.1878 \cdot 10^{-6}(x_6)^3 - 0.5005 \cdot 10^{-3}(x_6)$$

where

y = injury-accident rate

x_6 = volume, vehicles per hour

x_{24} = merges per mile

x_{26} = traffic lights per mile

x_{28} = vehicle miles per hour

The variables included in the above equation are those whose coefficients were significantly different from zero at the 95-percent level.

When all variables were included (equation not shown), the multiple correlation coefficient was only 0.2804, with standard error estimate of 30.53 and F-ratio of 7.603. The low multiple correlation coefficient and high F-ratio indicated that the variation remaining in the accident rate could not be ascribed purely to chance at the 95-percent level. For this reason, only the variables whose coefficients showed significant difference from zero were included in the above equation.

(2) Other-Divided Sections

The calculated regression equation was

$$y = 32.71 - 2.88(x_{20}) + 0.4319^{-3}(x_{22})^3 + 4.584 \cdot 10^{-4}(x_{28})$$

$$- 17.24 \cdot 10^{-3}(x_6) - 0.5337(x_{12})^2 - 0.9787(x_7)^3 - 0.959 \cdot 10^{-3}(x_{25})^2$$

where y = injury-accident rate

x_6 = volume, vehicles per hour

x_7 = truck percentage

x_{12} = length, miles

x_{20} = median width

x_{22} = driveways per mile

x_{25} = crossings (including traffic lights) per mile

x_{28} = vehicle miles, per hour

As before, the only variables included in this equation were those whose coefficients were significantly different from zero at the 95-percent level.

When all the variables were included in the equation (not shown) for the other-divided sections, the multiple correlation coefficient was 0.4204 with standard error of estimate of 30.16 and F-ratio of 7.784. Again, the low multiple correlation coefficient and high F-ratio indicated that not all variation in the accident rate could be ascribed purely to chance at the 95-percent level.

RESULTS OF BEFORE-AND-AFTER STUDY

Annual injury rates and AADT data were taken from the "State of New Jersey Highway Accident Factors" for the years 1950, 1951, 1952, 1953, 1954, 1957, 1958, 1960, and 1963.

The major difficulty in studying a road for an extended time before and after major modification is that other time-varying factors affect accident rates. The most serious, and the hardest to take into account, is

the change in the use pattern of a particular road section in relation to the highway network near it. More than volume is usually affected, since changes in truck percentage, changes in the character of rush-hour traffic, and changes in side friction can occur as the result of roadway modification and other factors. Even if there were an existing methodology to take all these factors into account, the resulting procedure would possibly be beyond the scope of this study. Here, only an over-all measure of possible changes was taken into consideration.

For each road section on which barriers were constructed during the years for which data were available, a "theoretical injury-accident rate" was postulated and compared with the actual injury-accident rate as given in "State of New Jersey Highway Accident Factors." This theoretical injury-accident rate was read from a graph fitted to plots of AADT versus injury-accident rates (for all road sections in a specific year) by the moving-average technique described in an earlier section. For a given AADT, this graph gives the average injury-accident rate for all road sections near that range of AADT.

The actual injury-accident rate was then divided by the average injury-accident rate, yielding a comparison ratio. This injury-accident ratio was then plotted against time in Figures 2 through 9, for the 52 road sections on which barriers were built between 1955 and 1962.

For each road section, the average of the injury-accident-rate ratios for an equal number of years before and after barrier installation is presented. The largest number of years for which data are available both before and after barrier construction is used. A percentage change from before to after is then shown, and the following classification into a five-point scale is made:

Classification	After-Ratio as a Percentage of Before Ratio
(1) Sharp decrease	Less than 55%
(2) Moderate decrease	Between 55% and 80%
(3) No change	Between 80% and 120%
(4) Moderate increase	Between 120% and 145%
(5) Sharp increase	Greater than 145%

According to this measure, the lower the percentage, the greater the safety improvement.

A tabulation of the results, by route and municipality, is presented in Table 3, below.

TABLE 3. BEFORE-AND-AFTER ANALYSIS

(Road Sections and Injury-Accident Ratios)

Road Section	Miles of Road	Miles of Barrier	Average Ratio Before Barrier	Average Ratio After Barrier	Percentage of Change in Ratio	Class
Route 1, 1/9, 1/9T						
Bergen County						
Palisades Park	0.86	0.86	0.350	0.585	167.2	5
Fort Lee	1.47	0.77	0.870	1.160	133.3	4
Union County						
Elizabeth	3.27	0.22	1.040	1.050	101.0	3
Hudson County						
Kearny	1.16	1.03	1.960	0.472	24.1	1
Jersey City 1/9	3.21	0.56	1.880	1.79	95.2	3
Jersey City 1/9T	2.27	0.10	1.135	1.350	118.9	3
Essex County						
Newark	5.63	0.62	0.840	1.290	153.6	5
Middlesex County						
Edison	5.85	0.54	0.950	0.846	89.1	3
New Brunswick	1.37	0.19	0.568	0.521	91.7	3
North Brunswick	5.79	5.13	0.711	0.690	97.0	3
South Brunswick	6.64	6.64	0.375	0.399	106.4	3
Plainsboro	2.17	2.17	0.426	0.192	45.1	1
Mercer County						
West Windsor	3.92	3.92	0.520	0.461	88.7	3
Lawrence	4.87	3.74	0.676	0.732	110.1	3
Trenton	2.66	1.94	2.080	0.331	15.9	1

Road Section	Miles of Road	Miles of Barrier	Average Ratio Before Barrier	Average Ratio After Barrier	Percentage of Change in Ratio	Class
Route 4						
Bergen County						
Fort Lee	0.85	0.50	1.433	0.978	68.2	2
Englewood	1.50	0.38	1.175	0.721	61.4	2
Teaneck	2.59	2.00	0.784	0.911	116.2	3
Hackensack	0.56	0.56	1.112	1.896	170.5	5
River Edge	0.40	0.28	1.578	1.330	84.3	3
Paramus	2.73	1.58	1.477	1.683	113.9	3
Route 17						
Bergen County						
Hackensack	0.61	0.55	1.377	0.665	48.3	1
Lodi	0.62	0.62	1.274	0.759	59.6	2
Maywood	0.24	0.24	0.814	1.627	200.0	5
Rochelle Park	1.18	1.18	1.138	0.620	54.5	1
Paramus	4.92	0.77	0.942	1.071	113.7	3
Route 20						
Passaic County						
Paterson	3.94	1.00	0.603	1.013	168.0	5
Route 22						
Union County						
Union	3.38	0.39	1.571	1.265	80.5	3
Hillside	1.83	1.83	1.288	0.831	65.5	2
Springfield	1.20	0.17	0.466	0.663	142.3	3
Scotch Plains	2.00	1.77	0.926	0.603	65.1	2
Mountainside	3.23	3.23	0.779	0.601	77.2	3*
Essex County						
Newark	1.89	0.79	0.727	0.628	86.4	3
Somerset County						
Green Brook	3.23	0.84	0.600	0.732	122.0	4
North Plainfield	3.40	3.40	1.035	0.769	74.3	2
Watchung	0.68	0.57	0.600	1.458	243.0	5

*This road section, although numerically in another class, was placed in the one indicated by inspection of the graphs.

Road Section	Miles of Road	Miles of Barrier	Average Ratio Before Barrier	Average Ratio After Barrier	Percentage of Change in Ratio	Class
Route 30						
Camden County						
Pennsauken	2.44	1.46	1.406	1.199	85.3	3
Route 38						
Camden County						
Delaware	3.01	0.45	1.582	1.859	117.5	4*
Route 46						
Bergen County						
Lodi	1.50	0.12	0.830	0.896	108.0	3
Hasbrouck Heights	0.72	0.26	0.384	0.522	135.9	4
Route 72						
Ocean County						
Stafford	9.75	1.09	0.614	0.710	115.3	3
Ship Bottom	0.57	0.05	0.798	0.614	76.9	2
Route 73						
Camden County						
Pennsauken	1.34	1.34	1.920	1.058	55.1	2
Burlington						
Cinnaminson	0.62	0.12	2.815	0.869	30.9	1
Palmyra	1.00	0.27	2.302	0.722	31.4	1
Maple Shade	3.30	1.13	0.513	0.662	129.0	4
Route 130						
Camden County						
Gloucester	0.95	0.08	1.168	0.933	79.9	2
Haddon	0.90	0.50	0.907	1.505	165.9	5
Brooklawn	1.05	0.68	1.306	0.490	37.5	1
Pennsauken	5.10	4.53	1.525	0.765	50.2	1
Route 322						
Atlantic County						
Hamilton	12.83	7.95	0.785	0.616	78.5	3*
Folsom	4.30	0.21	0.820	0.617	75.2	2

*This road section, although numerically in another class, was placed in the one indicated by inspection of the graphs.

Results of this study are summarized by classification in Table 4, following.

TABLE 4. BEFORE-AND-AFTER ANALYSIS
(Change in Injury-Rate Ratio)

	Sharp Decrease	Moderate Decrease	No Change	Moderate Increase	Sharp Increase
Number of sections	10	8	22	5	7
Miles of road	16.89	15.07	85.00	11.73	12.81
Miles of barrier	13.81	8.76	40.95	3.45	4.35
Percent of barrier	81.8%	58.1%	48.2%	29.4%	34.0%

The decreasing percentages in the percent-of-barrier line of the table, from the sharp-decrease column to the sharp-increase column, tend to indicate that the extension of barrier construction correlates well with a decreasing injury-accident ratio.

CONCLUSIONS

Although the data used for this study were in relatively poor form, and many extrapolations, interpolations, and approximations were required, the analyses tend to support the following conclusions:

(1) The New Jersey Concrete Barrier Curb is an effective means of separating automobile traffic in opposing roadways.

(2) Four-lane divided roads have significantly lower accident rates than similar undivided ones.

(3) Roads on which the barrier is installed have accident records as good as, if not better than, the accident records of roads which are divided by other means.

(4) The effect that the installation of a barrier has on accident rates is modified by the presence or absence of other roadway and traffic factors, particularly traffic lights, acceleration lanes, and deceleration lanes. As the number of these increases, the accident record of a road also tends to increase.

(5) The accident records of roads have improved in direct relation to the amount of barrier installed; in the before-and-after analysis, those road sections which show most improvement in injury-accident rates are the ones on which the greatest amount of barrier has been constructed.

(6) The parameters which most significantly affect variation in the injury-accident rates of sections divided by barriers are the number of traffic lights per mile* and the number of merges per mile. An increase in either of these road parameters on barriered roads tends to increase the injury-accident rate. A more complicated relationship

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*Also correlated was the number of intersections per mile. This was not listed separately, for in the category under study there was a one-to-one correspondence of lights and intersections.

(although a less significant one) exists between traffic volume and injury-accident rate.

(7) The parameters which most significantly affect the variation in the injury-accident rate of sections divided by means other than barriers are median width, number of driveways per mile, length of road section, truck percentage, number of crossings per mile, and volume. Increases in length, median width, truck percentage, and crossings per mile tend to decrease the injury-accident rate, although the effects of the latter two are small. An increase in driveways per mile tends to increase the injury-accident rate. The relationship to volume is, again, complicated.

(8) The effect of isolated detail in roadway design was not determined, because no accident could be located precisely within a municipality.

RECOMMENDATIONS

(1) The installation of the New Jersey concrete median barriers can be fully justified on the basis of this study. The barrier is an effective method of separating roadways to eliminate the head-on collision of automobiles. Other considerations, such as the amount of space available, may give it advantages over other median dividers. The accident records of roads on which the barriers have been installed are neither clearly superior nor clearly inferior to those of roads divided by other means, and the barriers may therefore be classed as one of the many possible dividers useful in increasing highway safety.

(2) The lack of detailed accident-location data seriously limits the study of accidents. It is therefore recommended that the recording of precise location be mechanized, so that this vital data can be made available for use in future studies.

(3) Since the historical analysis of accident records was seriously hampered by the lack of detailed information for years before 1961, it is recommended that a mechanism be established which will ensure the long-term maintenance of accident records.

(4) Since the summary accident data transferred to computer cards are very skimpy and make detailed accident analysis impossible, it is recommended that computer-card information be expanded to include more information, even at the expense of increasing the number of cards. The additional information should include on-site evaluation of accidents on the basis of character, number of cars or other objects involved in primary and secondary collisions, etc.

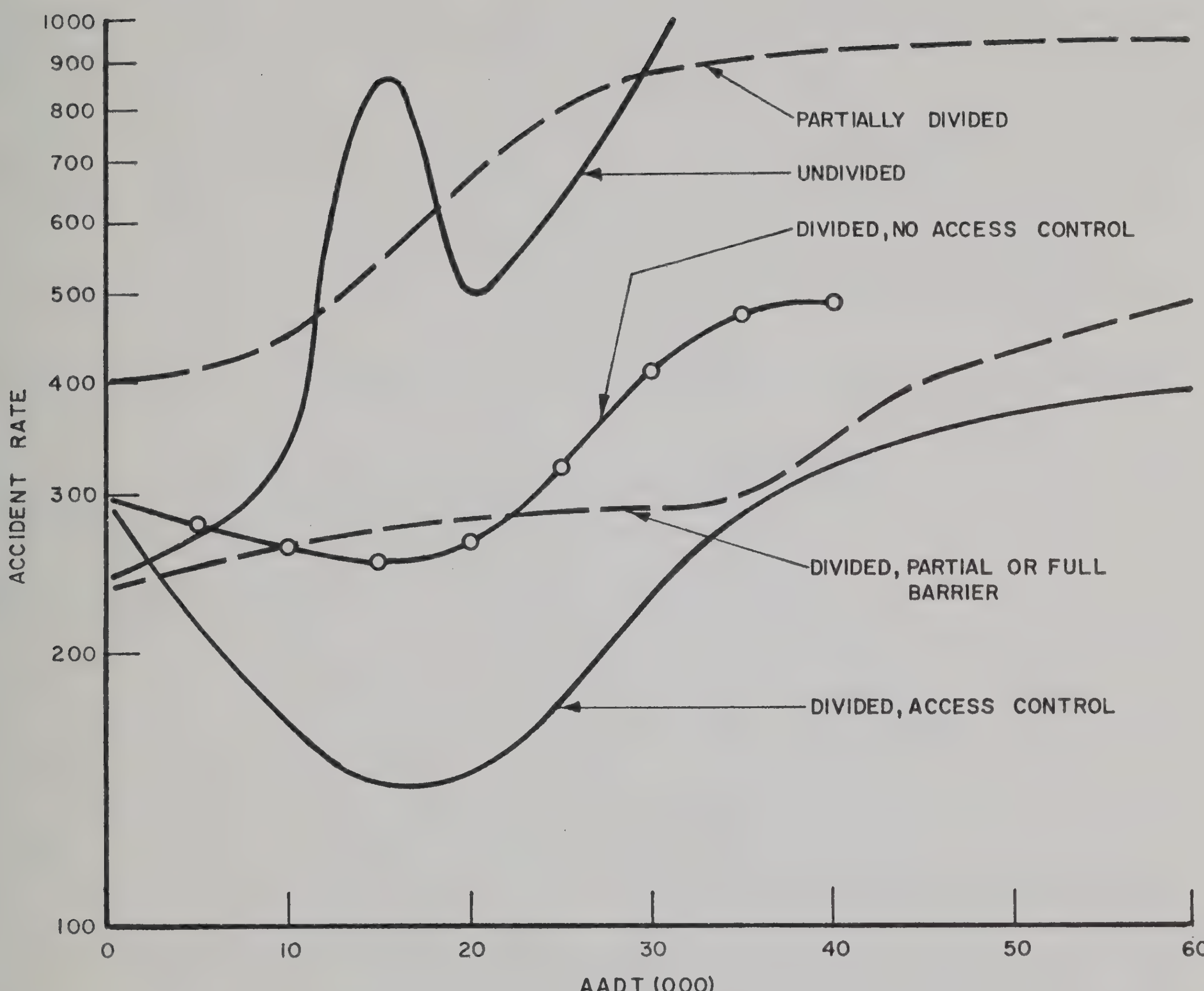

FIGURE 1. RELATIONSHIP BETWEEN ACCIDENT RATE AND AADT FOR CLASSES OF NEW JERSEY 4-LANE ROAD SECTIONS; 1963

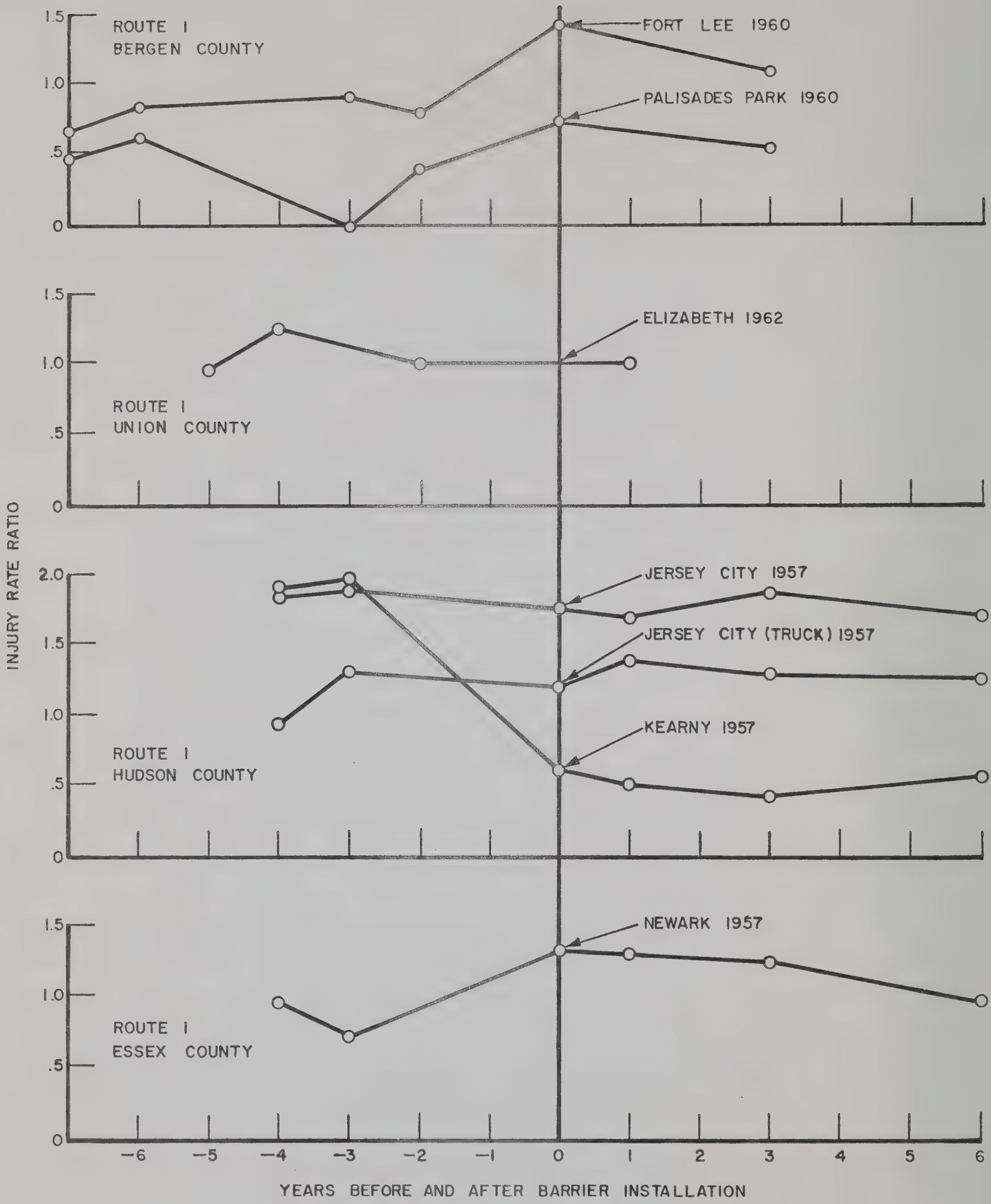

FIGURE 2. INJURY ACCIDENT RATE RATIO FOR SELECTED NEW JERSEY ROAD SECTIONS

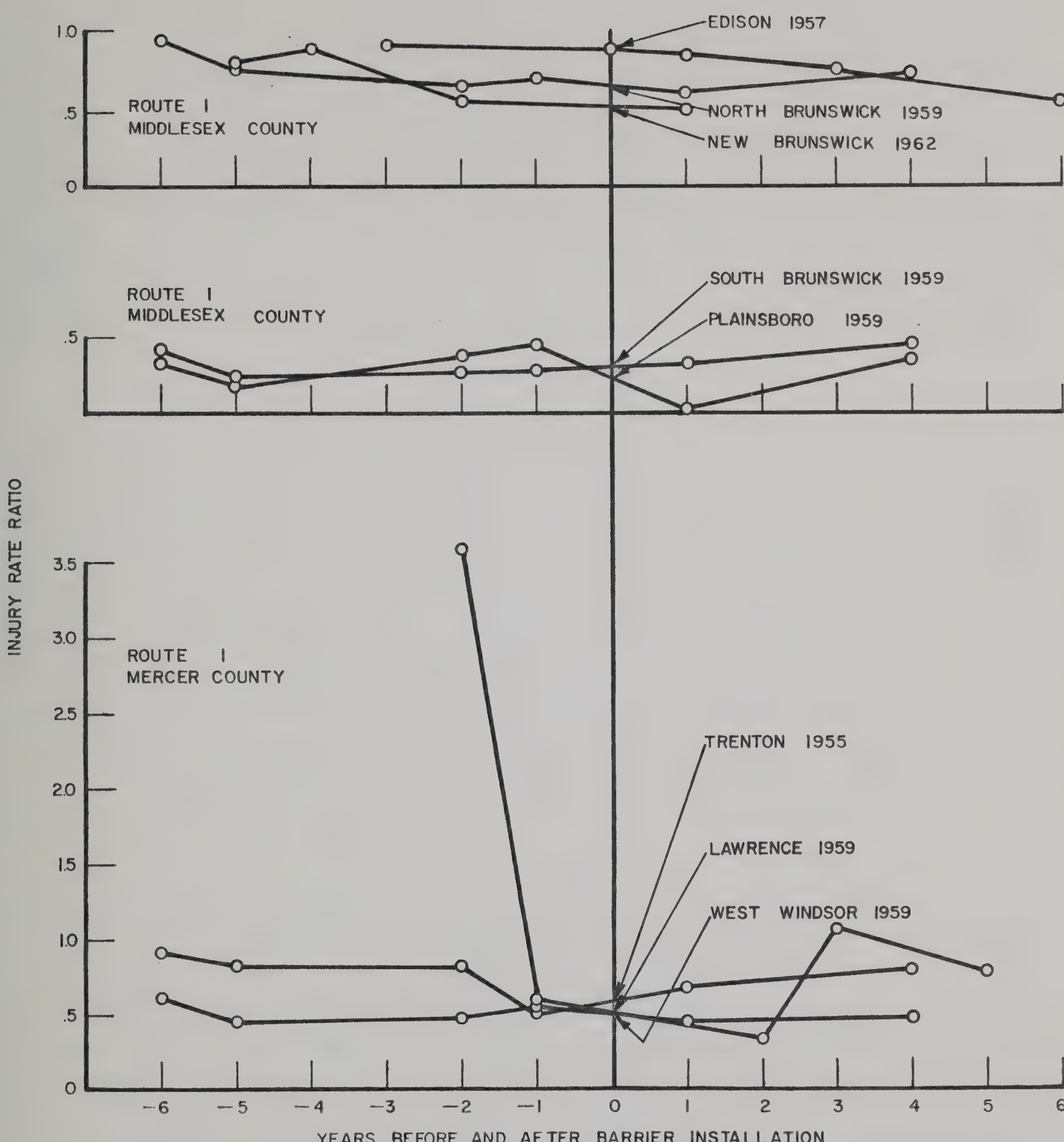

FIGURE 3. INJURY ACCIDENT RATE RATIO FOR SELECTED NEW JERSEY ROAD SECTIONS

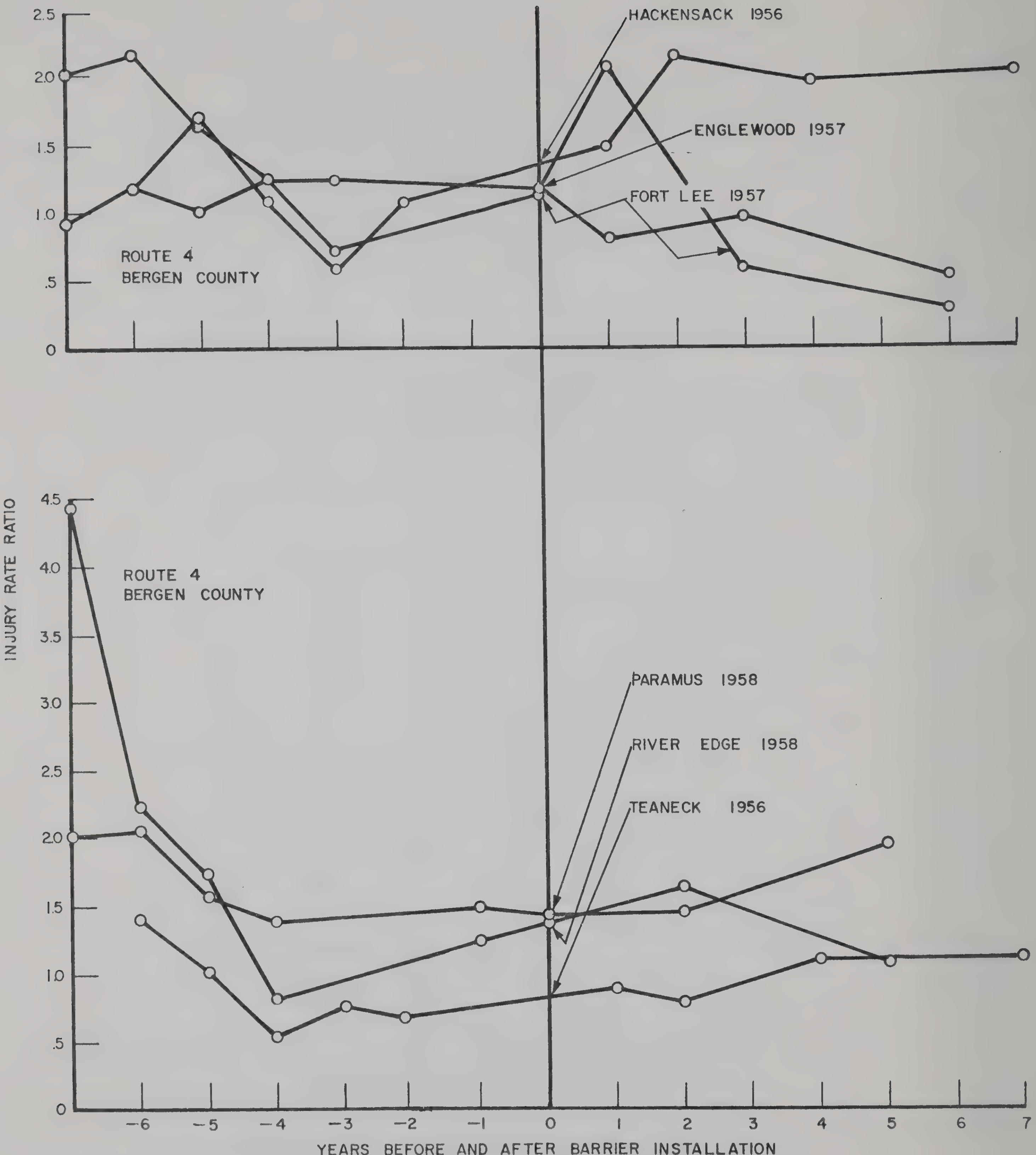

FIGURE 4. INJURY ACCIDENT RATE RATIO FOR SELECTED NEW JERSEY ROAD SECTIONS

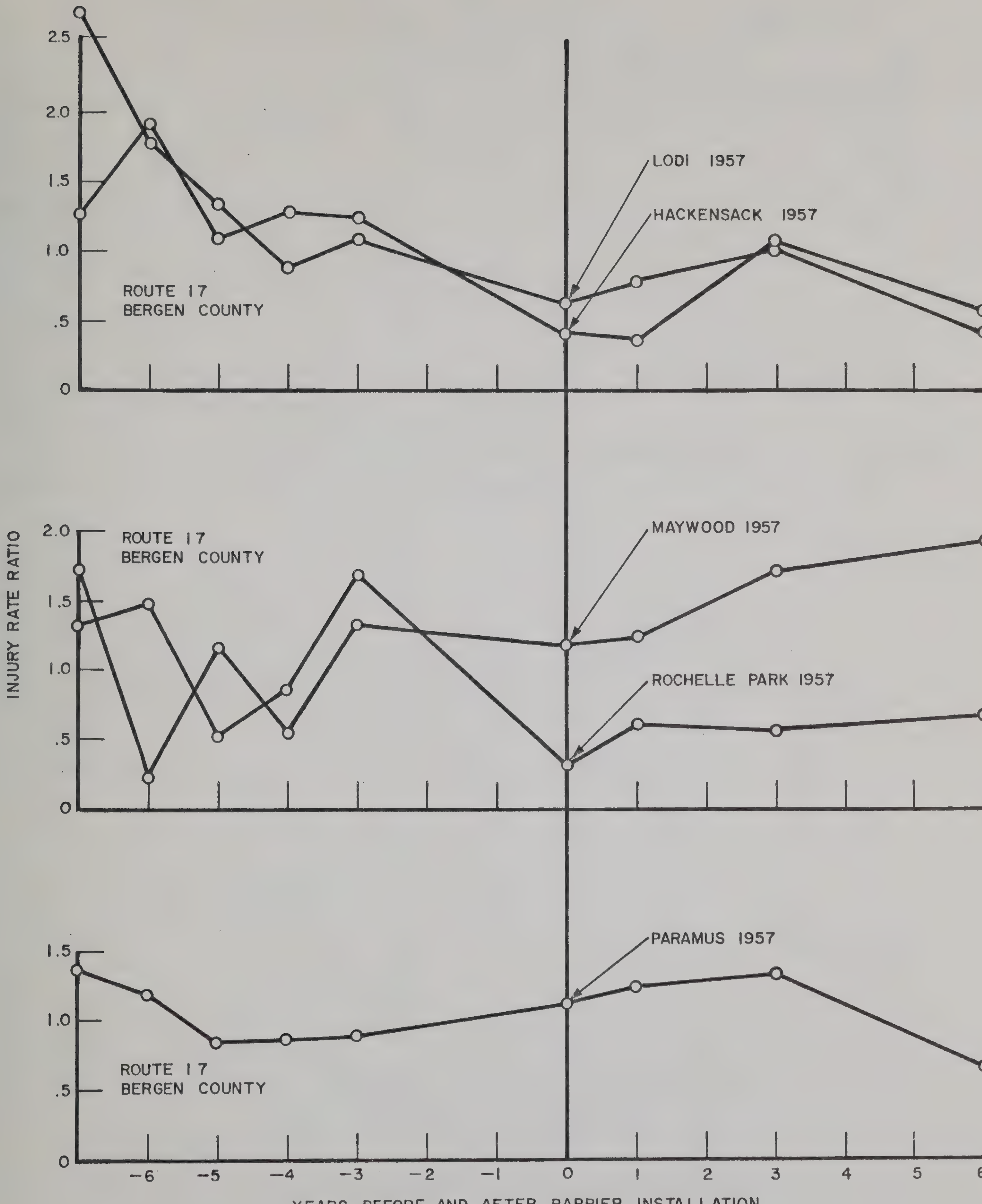

FIGURE 5. INJURY ACCIDENT RATE RATIO FOR SELECTED NEW JERSEY ROAD SECTIONS

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Hoboken, N. J.

HIGHWAY CENTER-BARRIER INVESTIGATION
Part I. Accident Analysis

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